

APPLICATION OF MAGNETIC FIELD FOR REDUCTION OF SLUDGE
BULKING IN ACTIVATED SLUDGE SYSTEM

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Dedicated to my precious love

ABANG, KHAYLA ZAHRA, MAK & AYAH

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ABSTRACT

Activated sludge treatment process is the most commonly used technology in treating municipal wastewater. Nevertheless, its stable operation is always plagued by occurrence of sludge bulking. Existing control approaches have led to various drawbacks and caused more problematic issues in the treatment system. Therefore, this study investigated the use of magnetic field on activated sludge in controlling the occurrence of sludge bulking and to further enhance wastewater treatment process. The initial stage of the study involved batch tests where statistical experimental design was implemented. Factorial design was carried out first, followed by central composite design experiment. The studies showed that turbidity reduction, aggregation and settling velocity of the activated sludge were affected by factors of magnetic field, exposure time, biomass concentration and mixing intensity. Interaction effects between the factors were also observed. Statistical models describing relationship between the variables were developed. From the study, the highest turbidity reduction (89.1%), aggregation (97.8%) and settling velocity (0.68 cm/min) were achieved under optimal condition of 88.0 mT magnetic field, 16.5 hrs exposure time, 2800 mg/L biomass concentration and 300 rpm mixing intensity. The following stages of the study were conducted in 6 L column reactors. The reactors were operated under long period of sludge retention time of 20 days and in deficient dissolved oxygen of less than 2 mg/L in order to induce the sludge bulking phenomenon. After reaching its stable state, the activated sludge under the magnetic field exposure showed significant results as compared to without the exposure. The average aggregation and settling velocity for the magnetically exposed activated sludge were 89% and 0.59 m/hr as compared to 68% and 0.50 m/hr for the unexposed sludge. Such properties resulted in significant enhancement of sludge volume index at 23.7 mL/g for magnetically exposed activated sludge as compared to 72.2 mL/g for the unexposed sludge. This enhancement benefited the treatment performances whereby the average chemical oxygen demand, ammonia and total phosphorus removal were 87%, 88% and 72% under the magnetic field exposure as compared to 67%, 75% and 44%, respectively without the exposure. Magnetically exposed activated sludge also contained high content of tightly bound extra-cellular polymeric substances (95.6 mg/g VSS) compared to unexposed sludge (61.8 mg/g VSS). Finally, Next Generation Sequencing analysis indicated that magnetically exposed activated sludge showed less possibility of filamentous microorganisms presence compared to the unexposed activated sludge. Overall, analysis confirmed that magnetic field could enhance the settling property of activated sludge through improvement on its aggregation and bioflocculation capability. These imply that magnetic field is reliable for accelerating activated sludge settleability, hence enhancing performance efficiency of the treatment systems. The applied magnetic field was also proven to inhibit proliferation of filamentous microorganisms, thus has potential to inhibit occurrence of sludge bulking.

ABSTRAK

Proses rawatan enapcemar teraktif adalah teknologi yang lazim digunakan dalam merawat sisa air kumbahan perbandaran. Namun begitu, operasinya yang stabil kerap terganggu oleh masalah pukal enapcemar. Pendekatan kawalan sedia ada membawa kepada pelbagai kelemahan dan mengakibatkan lebih banyak masalah kepada sistem rawatan. Justeru itu, kajian ini menyiasat penggunaan medan magnet terhadap enapcemar teraktif dalam mengawal masalah pukal enapcemar dan meningkatkan keberkesanan proses rawatan sisa air. Di awal kajian, kaedah reka bentuk eksperimen statistik dilaksanakan. Kaedah reka bentuk berfaktor dijalankan terlebih dahulu, diikuti dengan kaedah reka bentuk komposit pusat. Kajian ini menunjukkan bahawa pengurangan kekeruhan, pengagregatan dan halaju pengenapan enapcemar teraktif dipengaruhi oleh faktor medan magnet, masa pendedahan, kepekatan biojisim dan intensiti pembauran. Kesan interaksi yang wujud antara faktor juga diperhatikan. Beberapa model statistik dibina bagi menghubungkan faktor-faktor yang dikaji. Daripada kajian ini, pengurangan tertinggi kekeruhan (89.1%), pengagregatan (97.8%) dan halaju pengenapan (0.68 cm/min) telah dicapai pada keadaan optimum medan magnet 88.0 mT, masa pendedahan 16.5 jam, kepekatan biojisim 2800 mg/L dan intensiti pembauran 300 rpm. Kajian seterusnya dijalankan dalam reaktor berisipadu 6 L. Reaktor tersebut beroperasi dalam tempoh masa tahanan enapcemar yang panjang iaitu selama 20 hari dan dengan oksigen terlarut rendah pada kepekatan kurang daripada 2 mg/L bagi menghasilkan fenomena pukal enapcemar. Selepas mencapai keadaan stabil, enapcemar teraktif di bawah pendedahan medan magnet menunjukkan hasil yang ketara berbanding tanpa pendedahan. Purata pengagregatan dan halaju pengenapan bagi enapcemar teraktif di bawah dedahan medan magnet adalah 89% dan 0.59 m/h berbanding 68% dan 0.50 m/h bagi enapcemar tanpa dedahan. Hal ini menghasilkan peningkatan besar dalam indeks isipadu enapcemar iaitu 23.7 mL/g bagi enapcemar teraktif di bawah dedahan medan magnet berbanding 72.2 mL/g bagi enapcemar tanpa dedahan. Peningkatan ini memberi manfaat kepada penyingkiran permintaan oksigen kimia, ammonia dan jumlah fosforus iaitu 87%, 88% dan 72% di bawah dedahan medan magnet berbanding 67%, 75% dan 44% dengan tanpa pendedahan. Enapcemar teraktif di bawah dedahan medan magnet juga mengandungi tinggi kandungan bahan polimer tambahan sel yang kuat terikat (95.6 mg/g VSS) berbanding enapcemar tanpa dedahan (61.8 mg/g VSS). Analisis Penjujukan Generasi Terkini juga menunjukkan bahawa enapcemar teraktif di bawah dedahan medan magnet mempunyai kurang kehadiran mikroorganisma berserabut berbanding enapcemar yang tidak terdedah. Secara keseluruhan, analisis mengesahkan bahawa medan magnet boleh meningkatkan halaju pengenapan enapcemar teraktif melalui peningkatan pada keupayaan penggumpalan. Ini menunjukkan bahawa medan magnet mampu meningkatkan keupayaan enapan enapcemar teraktif sekaligus, meningkatkan kecekapan prestasi sistem rawatan. Keupayaan kesan medan magnet juga terbukti dalam menghalang pembiakan mikroorganisma berserabut, dan seterusnya berpotensi untuk menghalang berlakunya masalah pukal enapcemar.

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LIST OF ABBREVIATIONS

ASP	-	Activated sludge process
SRT	-	Sludge retention time
DO	-	Dissolved oxygen (mg/L)
SBR	-	Sequential/Sequencing batch reactor
CCD	-	Central Composite Design
EPS	-	Extra-cellular polymeric substances
RSM	-	Response surface methodology
MLSS	-	Mixed liquor suspended solids (mg/L or g/L)
MLVSS	-	Mixed liquor volatile suspended solids (mg/L or g/L)
SVI	-	Sludge volume index (mL/g)
COD	-	Chemical oxygen demand (mg/L)
ESS	-	Effluent suspended solids (mg/L or g/L)
VSS	-	Volatile suspended solids (mg/L or g/L)
NGS	-	Next Generation Sequencing
HGMS	-	High gradient magnetic separation
EMF	-	Electromotive force
MTD	-	Magnetic treatment device
PHAs	-	Polyhydroxyalkanoates
PHB	-	Poly-3-hydroxybutyrate
PHV	-	Poly-3-hydroxyvalerate
HB	-	Hydroxybutyrate
HV	-	Hydroxyvalerate
DNA	-	Deoxyribonucleic acid
PB	-	Prussian blue
FA	-	Formaldehyde (mg/L)

NdFeB	-	Neodymium-Iron-Boron
FISH	-	Fluorescence in situ hybridization
F/M	-	Food-microorganisms ratio
BOD	-	Biochemical oxygen demand
WWTP	-	Wastewater treatment plant
RAS	-	Return activated sludge
FI	-	Filamentous index
RBCOD	-	Readily biodegradable substrates
PAX-14	-	Polyaluminium chloride
SSVI	-	Stirred specific volume index
SRF	-	Specific resistance to filtration
EPS _s	-	Soluble Extra-cellular polymeric substances
EPS _b	-	Bound Extra-cellular polymeric substances
SV ₃₀	-	Sludge volume
AOP	-	Advanced oxidation process
TN	-	Total nitrogen (mg/L)
IWK	-	Indah Water Konsortium
ANOVA	-	Analysis of variance
TP	-	Total phosphorus
OUR	-	Oxygen uptake rate
SOUR	-	Specific oxygen uptake rate
Ag	-	Aggregation (%)
PVSK	-	Polyvinylsulfuric acid potassium salt
HRT	-	Hydraulic retention time
VER	-	Volumetric exchange rate
RH	-	Relative hydrophobicity (%)
SC	-	Surface charge (meq/g MLSS)
DLVO	-	Derjaguin and Landau, Verwey and Overbeek theory
OLR	-	Organic loading rate
AOB	-	Ammonium oxidizing bacteria
PAOs	-	Phosphorus accumulating organisms
VFAs	-	Volatile fatty acids
FESEM	-	Field Emission Scanning Electron Microscopy
TSS	-	Total suspended solids (mg/L or g/L)

AN	-	Ammonia-nitrogen (mg/L)
BSA	-	Bovine serum albumin
FC	-	Folin-Ciocalteu
16S rRNA	-	16 subunit ribosomal ribonucleic acid
LB-EPS	-	Loosely-bound Extra-cellular polymeric substances
TB-EPS	-	Tightly-bound Extra-cellular polymeric substances
PCR	-	Polymerase chain reaction
EPS _T	-	Total Extra-cellular polymeric substances
PN/PS	-	Protein-to-Polysaccharides ratio

LIST OF SYMBOLS

M	-	Magnetization of a particle
χ_v	-	Magnetic susceptibility of the molecules' electrons
H	-	Applied magnetic field (emu/cm ³)
E	-	Energy of magnetic gradient
V	-	Volume of the material
F	-	Magnetic interaction force
χ_o	-	Magnetic susceptibility of the magnetized material
dH/dx	-	Difference of the magnetic field strength with distance
T_i	-	Turbidity influent (FNU)
T_f	-	Turbidity effluent (final) (FNU)
T_0	-	Turbidity at 0 min (FNU)
$\mu_{overall}$	-	Overall specific biomass growth rate (day ⁻¹)
k_d	-	Endogenous decay rate (hour ⁻¹)
Y_{obs}	-	Observed biomass yield (mg VSS/mg COD)
Y	-	Theoretical biomass yield (mg VSS/mg COD)
θ	-	Sludge retention time (d)
dO_2/dt	-	Oxygen uptake rate
O_x	-	Theoretical COD (1.42 mg O ₂ /mg biomass)
M	-	Biomass concentration (mg VSS/L)
X_e	-	Effluent volatile suspended solids (mg/L)
C_i	-	COD concentration in the influent (mg/L)
C_e	-	COD concentration in the effluent (mg/L)
X_r	-	Mixed liquor volatile suspended solid in reactor (mg/L)
V_T	-	Total working volume in reactor (L)
Q_e	-	Effluent flow rate (L/d)

LIST OF APPENDICES

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CHAPTER 1

INTRODUCTION

1.1 Preamble

Activated sludge system was developed in the early 1900s. Since then, it has been the most frequently used process in various wastewater treatment technologies. In general, activated sludge process (ASP) is comprised of two stages which are biological degradation that occurs in an aeration tank, and the physical stage, which takes place in a secondary clarifier. The key feature of the biological degradation process is the responsible bacteria in converting the incoming organic pollutants into the purified water that later, has to be separated from the liquid portion by gravity. The performance of ASP is therefore, relies on bacterial activity and efficient solid-liquid separation as to guarantee good effluent quality being discharged from the system (Clauss *et al.*, 1998).

Even though ASP has been the most commonly used technology in treating municipal and industrial wastewaters, its stable operation is still plagued by the solid-liquid separation problem (Martins *et al.*, 2011) caused by the occurrence of sludge bulking. The primary factor that was reported to induce the bulking is the excessive proliferations of the filamentous microorganisms. The abundances of the filaments

have physically prevent the close packing of activated sludge flocs thus cause severe interferences to the separation and settling activities in the treatment process (Lou and De los Reyes, 2008). Such interferences lead to the deterioration of the effluent quality and sludge wash out in the final treated effluent. The sludge bulking occurrence can also become more critical as it can fail the overall treatment system performances particularly in terms of removal ability of the pollutants (Martins *et al.*, 2004a).

For the purpose of enhancing the wastewater treatment processes, various approaches have been used including magnetic field application. This approach has been applied for removal of turbidity and suspended solids (Johan, 2003; Chin *et al.*, 2006), organic compounds (Yavuz and Çelebi, 2000; Ji *et al.*, 2010; Łebkowska *et al.*, 2011), nutrients consists of nitrogen and phosphorus compounds (Liu *et al.*, 2008; Merino-martos *et al.*, 2011) and toxic chemicals (Jung *et al.*, 1993). As to ensure higher effectiveness of these removals, microorganisms have to act efficiently in order to degrade the organic pollutants, resulted in good solid-liquid separation and settling processes. However, provocation by the filamentous sludge bulking can disturb these processes thus cause reduction in removal performances of the wastewater treatment. Through the application of magnetic field, the treatment processes have been proven to be enhanced. These enhancements are resulted from the significant influence of the magnetic field towards the bacterial activity, thus indirectly indicates that it may also potential to control the filamentous sludge bulking problem.

To the recent knowledge, none of the research has been carried out to investigate the effect of magnetic field application towards the sludge bulking especially in terms of filamentous microorganisms' proliferations in the ASP. The existing approaches used to control the sludge bulking were evidenced to exhibit various drawbacks that relatively caused more problems to the ASP. The approaches such as chlorine addition were not sustainable as it only transferring one problem (sludge bulking) to another problem (i.e. increase of sludge wastage), which at the

end cause various adverse effects to the environment. Additionally, effect of the approaches is only instantaneously functioned. Once the control effect is halted, the sludge settleability will worsen, and the recovery of the treatment system will consumed lots of time and costs.

Therefore, this study is aimed to investigate the potential approach of the magnetic field in controlling the sludge bulking occurrences, thus further improving the separation and settleability of the activated sludge. As to achieve the aim, physical properties of the activated sludge are first been studied with regards to the variation of magnetic field effects. Furthermore, parameters that are known to induce the sludge bulking; sludge retention time (SRT) and dissolved oxygen (DO) concentration are been further investigated in terms of the characterization of the physical, biological properties and removal ability of the activated sludge. Susceptibility of the filamentous microorganisms towards the magnetic field were also being investigated.

1.2 Objectives of the Study

The specific objectives of this study are:

- i. To investigate the potential effects of magnetic field in terms of its intensity and exposure time towards physical properties of the activated sludge.
- ii. To determine the effect of magnetic field on the physical properties, removal ability and microbial activity of activated sludge subjected to long sludge retention time (SRT).

- iii. To investigate the effect of magnetic field on the characteristics of activated sludge bulking subjected to low dissolved oxygen (DO) concentration.
- iv. To investigate the susceptibility of filamentous microorganisms in the activated sludge bulking under magnetic field.

1.3 Scope of the Study

This study focused on the activated sludge bulking under the effect of magnetic field. The range of magnetic field intensity used in this study was 15 mT and 88 mT. These magnets were attached to a laboratory-scale reactor system which its design was based on the sequential batch reactor (SBR) system. All of the experiments were conducted in Environmental Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM). The wastewater and activated sludge samples were both collected at Indah Water Konsortium (IWK) Treatment Plant, Pulau Emas, Johor. The type of wastewater used throughout the study were raw domestic wastewater.

This study involved batch tests experiments in small working volume of 250 mL. These experiments involved the use of statistical experimental design in order to investigate the significance between the variables of magnetic field, exposure time, biomass concentration and mixing intensity on the physical properties of activated sludge. Consequent experiments were conducted using reactor systems with working volume of 6 L. There were two reactors used throughout the study. Reactor A was an experimented reactor that comprised attached series of permanent magnets while Reactor B was acted as control reactor that have no magnets. For the purpose of studying the activated sludge bulking, the reactors were set in two conditions. For the

first condition, the sludge retention time (SRT) was set at longer period of about 20 days. Later, for the second condition, the dissolved oxygen (DO) was set at concentration of less than 2 mg/L. The final study was then focused on the characteristics of filamentous microorganisms, its abundances and production of extra-cellular polymeric substances (EPS).

1.4 Significance of the Study

Activated sludge bulking is among the operational problems that commonly occurred in the treatment plants worldwide. Various control strategies such as increasing DO concentration, adding chlorine or metal salts have been reported by many researchers in inhibiting the occurrence of sludge bulking (Xie *et al.*, 2007; Li *et al.*, 2011; Guo *et al.*, 2012a). However, these control strategies led to various drawbacks that consequently exhibited more problematic issues to the treatment plants (Juang, 2005; Rossetti *et al.*, 2005; Xie *et al.*, 2007; Guo *et al.*, 2012a). Apparently, the application of magnetic field in inhibiting the sludge bulking has not been explored yet. Therefore, the significance of this study can be listed as follows.

- i. The study provides the design and procedural input of a laboratory scale SBR system, fabricated to allow attachment of magnetic devices which comprised series of permanent magnets.
- ii. The study provides the effect of applying magnetic field with intensity 88 mT in the sludge bulking conditions at long SRT of 20 days and low DO concentration of less than 2 mg/L.

- iii. The study provides the effect of magnetic field on the biokinetic properties of activated sludge including growth rate (μ), endogenous decay rate (k_d), observed biomass yield (Y_{obs}) and theoretical biomass yield (Y) under the condition of sludge bulking.
- iv. The study also provides the effect of magnetic field in inhibiting the proliferation of filamentous microorganisms and limiting the growth of its filaments, thus able to reduce the occurrence of sludge bulking.
- v. The study provides the effect of magnetic field in enhancing the production of EPS and its chemical constituents despite the condition of sludge bulking.

1.5 Organization of Thesis

The thesis is presented in seven chapters. Chapter 1 provides the overview of the problems generated in the activated sludge wastewater treatment and the conditions of the sludge bulking that concurrently hinder the efficiency of the treatment process. This chapter also points out the significant of the magnetic field in potentially inhibits the occurrence of the sludge bulking in ASP system. The literature review is presented in Chapter 2. This chapter highlights the occurrence of sludge bulking and the factors that cause its occurrence. The approaches used to control this sludge bulking problem and consequent drawbacks are also been emphasized in this chapter. Additionally, this chapter also covers the application of magnetic field in water and wastewater treatment systems. The mechanisms of magnetic field contributed to the various processes in the treatment systems are also

been deliberated. At the end of this chapter, a knowledge gap is highlighted showing the potential of magnetic field in inhibiting the sludge bulking.

Chapter 3, 4, 5, and 6 present the works that have been conducted in this study. Chapter 3 presents the study on the preliminary investigation involving the magnetic factors towards the physical properties of the activated sludge. Chapter 4 and Chapter 5 are both focusing on the performances of magnetically-modified ASP bioreactor system that were run under the factor of SRT and DO concentration, respectively as to induce the filamentous sludge bulking condition. Chapter 6 presents the detail study on the filamentous microorganisms particularly on its abundances, micro-structures and EPS. Figure 1.1 presents the overall outline of the experimental works involved. Finally, Chapter 7 presents the conclusions of the study. This chapter also provides recommendation for future research exploration in relation to the findings of the study.

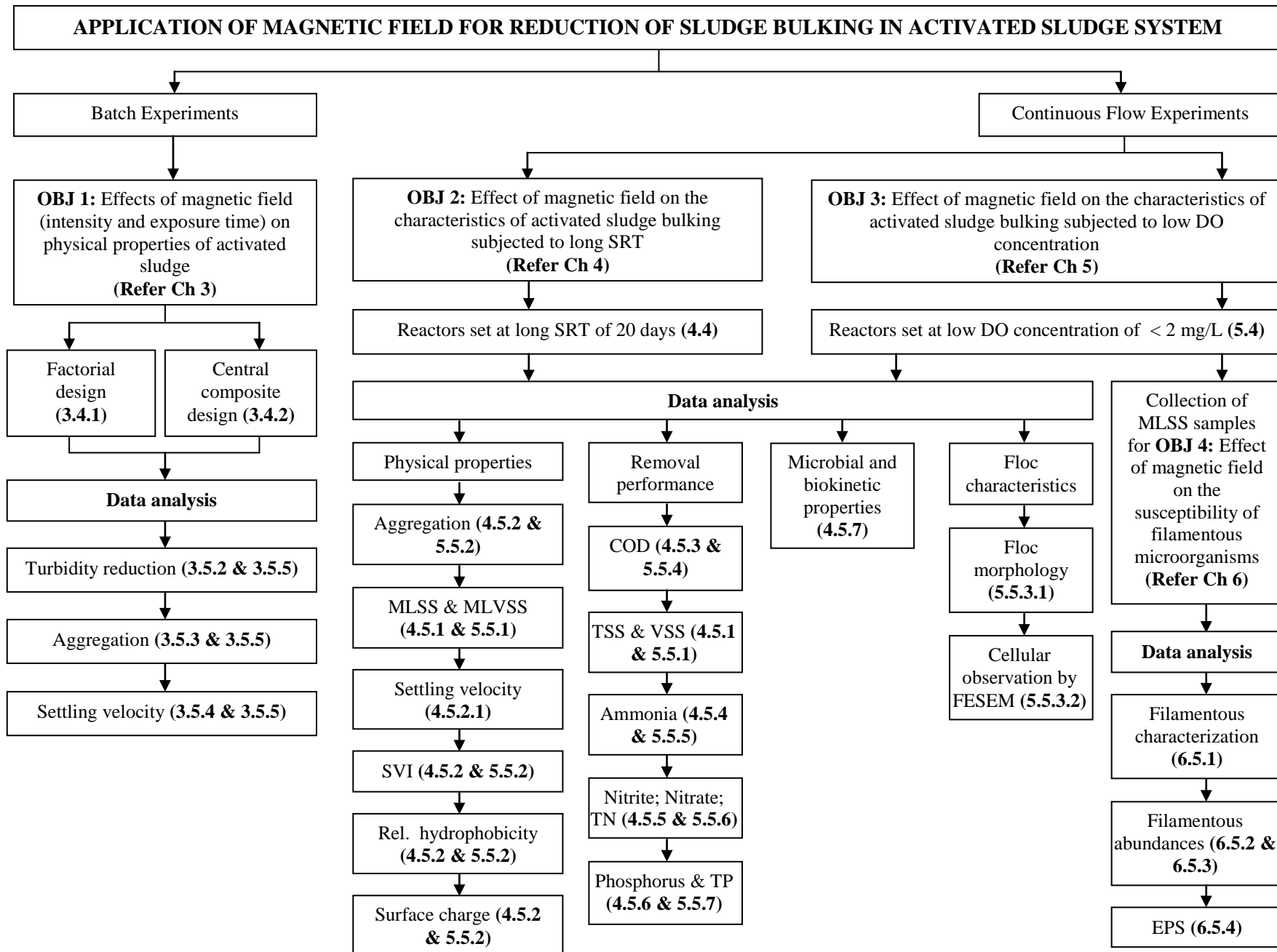


Figure 1.1 Outline of the experimental research works

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